LEAF AREA INDEX AND COVER OF SHORTGRASS STEPPE USING AVIRIS IMAGERY

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1. INTRODUCTION

Management of rangelands in the western United States requires data on vegetation community type, vegetation cover and productivity, and erosion potential in order to assess the sustainability of livestock grazing for food production. Remotely sensed imagery can provide attributes related to these data requirements over large areas. The Wyoming Hyperspectral Imagery Pilot Project was initiated in 1995 to determine the relationships between remotely sensed attributes and management data requirements using the best NASA sensor (at the time), the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) from the Jet Propulsion Laboratory (Green et al., 1998). The radiometric, spectral, and spatial characteristics of AVIRIS allow image degradation to simulate operational sensors such as the Landsat Thematic Mapper and Advanced Very High Resolution Radiometer.

Bare soil cover, which is related to erosion potential, and vegetation cover can be determined from hyperspectral imagery using the method of spectral endmember unmixing (Roberts et al., 1998). Endmembers must be spectrally distinct. Unfortunately most semi-arid vegetation have similar spectral signatures so determination of the cover fraction contributed by each species to the community composition is probably not feasible, except for some species (McGwire et al., 2000; Parker Williams and Hunt, 2001). However, green vegetation cover, non-green vegetation cover (litter), and bare soil are important community attributes directly applicable for rangeland management.

Vegetation productivity and leaf area index (LAI) are usually estimated using remotely sensed vegetation indices, particularly the Normalized Difference Vegetation Index (NDVI):

$$NDVI = (R_{NIR} - R_{Red})/(R_{NIR} + R_{Red}) \qquad (1)$$

where R_{NIR} is the reflectance in the near infrared and R_{Red} is the reflectance of red wavelengths. Preliminary analyses of AVIRIS data over the Agricultural Research Service's (ARS) Central Plains Experimental Range (CPER), a shortgrass steppe community near Nunn, Colorado, showed that NDVI were equal over a large range of biomass maintained by grazing intensity (Hunt, 2000). Various models of canopy reflectance show that fractional vegetation cover is an important variable determining NDVI (Carlson and Ripley, 1997; Myneni and Williams, 1994; Rondeaux et al., 1996). In particular, the SAIL model (Verhoef, 1984) has been used extensively to examine the responses of vegetation indices such as the NDVI to different variables (Baret and Guyot, 1991; Rondeaux et al., 1996). In addition to the SAIL model, reflectances of stacked leaves provide an empirical method to approximate changes of reflectance with increasing LAI, and when included in a two-component mixture model, could help elucidate the interactions between cover and LAI affecting NDVI.

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2. METHODS

AVIRIS data were obtained over the CPER on two dates, 25 July 1995 and 6 August 1998. The first year had abnormally high amounts of summer precipitation, whereas the second year had normal amounts of summer rain. The vegetation of CPER is shortgrass steppe, which is dominated by blue grama grass (*Bouteloua gracilis*). There is a long-term grazing intensity experiment (Figure 1) with three stocking levels (high, medium, and light) in 0.5 mile^2 pastures, which strongly determine the amount of standing biomass (Hart and Ashby, 1997). The heavy-grazed pasture has a permanent water hole; all data surrounding this water hole were excluded from data analyses by defining regions of interest and using the statistics from only these areas. Furthermore, all dirt roads in each pasture were excluded from the regions of interest. The final treatment is the large number of permanent plots where cattle grazing has been excluded. Species composition, biomass and cover data of these four areas are routinely collected; LAI was calculated from biomass using a specific leaf area of 9 m^2 kg^{-1}.

The flightline of the ER2 aircraft was east to west in 1995 and south-east to north-west in 1998; these flightlines resulted in a brighter northern edge of the image resulting from the sun-ground-sensor geometry and the vegetation bidirectional reflectance distribution functions. Fortunately, all the grazing experiments were near nadir in both flightlines. The atmospheric correction program, ATREM version 3.1 (Gao et al., 1993), was used to calculate surface reflectances from the calibrated AVIRIS radiances. Then an empirical line correction was applied to the data using a dark target (US Highway 85) and a bright target (a gravelly dry bare stream bed of Owl Creek, near the CPER Headquarters). The ground reflectances of these targets were acquired on 21 June 2000 using an Analytical Spectral Devices Inc. (ASD) FieldSpec Pro spectroradiometer (350 to 2500 nm), and averaged into the 224 AVIRIS bands using the calibrated wavelength files for each year. NDVI was calculated from the final reflectances using AVIRIS bands 53 (846 nm center wavelength) and 33 (664 nm center wavelength).

Four endmembers were used for spectral unmixing: bare soil, leaf litter, green vegetation, and shadow (Roberts et al., 1998). In both images, there were areas of plowed fields and recently harvested grain crops for the soil and litter endmembers, respectively. The vegetation endmember was obtained from the AVIRIS data in riparian areas with lush vegetation and deep soils. Finally the shadow endmember was assumed to be 1% reflectance for all wavelengths.

On 21 June 2000, transmittances and reflectances of stacked sunflower (*Helianthus annuus*) leaves were measured using the ASD FieldSpec Pro spectroradiometer. Because the spectral characteristics change rapidly when leaves are removed from the plant, fresh leaves were used for each new series of stacked leaves. Reflectances of the soil background were also measured, and the results were used in the SAIL model (Verhoef, 1984; M. Kim, personal communication). The leaf angle distribution was set to be entirely planophile. NDVI were also calculated for specific mixtures of LAI (from the stacked reflectances) and plant-soil cover. For total reflectance at either the 660 and 850 nm wavelengths (R_λ):

$$R_\lambda = (1 - f)\, R_{soil} + f\, R_{LAI} \qquad (2)$$

where f is the fraction covered by green leaves, R_{soil} is the soil reflectance, and R_{LAI} is the reflectance of the leaf stack where LAI equals the number of stacked leaves. The fraction f was varied from 0 to 1 in increments of 0.1; NDVI was then calculated from Eq. 1.

3. RESULTS AND DISCUSSION

The average green vegetation cover was not significantly different among treatments for either year, with the average cover for 62% in 1995 and 55% in 1998. In 1995, measured aboveground biomass were 86.4, 106.7 and 175.3 g dwt m^{-2}, and in 1998, measured biomass were 129.8, 130.7, and 159.8 g dwt m^{-2} for the heavy, medium and light grazed pastures, respectively. This translates to LAI from 0.8 to 1.5 m^2 m^{-2} for the lowest to highest aboveground biomass. The non-grazed permanent plots had an LAI of 1.8 m^2 m^{-2} for 1995, which was assumed to be the LAI in 1998.

The AVIRIS average reflectance spectrum for heavy-grazed pasture was highest at almost all wavelengths and the average reflectance spectrum for the non-grazed permanent plots was lowest at the visible and near-infrared wavelengths (Figure 2). The fraction of green vegetation cover from the endmember unmixing was approximately equal to the actual vegetation cover. The differences between the AVIRIS spectra in Figure 2 were from differences in the shadow endmember fraction. The amount of shadow followed one-to-one the amount of shrub cover on the plots (Figure 3).

NDVI were not correlated with LAI (Figure 4), and NDVI were weakly correlated with cover (data not shown). SAIL model predictions of NDVI for a grassland canopy are also shown on Figure 4, indicating that the range of LAI from 0.8 to 1.8 m^2 m^{-2} should have a large increase in NDVI. The weak correlation between NDVI and cover may simply be the result from the small variation of the independent variable, because when the data from other pastures during 1995 are included (no biomass/LAI data are available for these pastures), the correlation increases with an R^2 of 0.72.

For stacked sunflower leaves, reflectances at visible wavelengths decreased and the reflectances at NIR wavelengths increased as the number of leaves increased from one to four (Figure 5). Reflectances at 660 nm and 850 nm were used to calculate NDVI. For a planophile canopy, NDVI predicted for LAI of 1, 2, 3, and 4 m^2 m^{-2} by the SAIL model were similar to the NDVI for stacks of one, two, three and four leaves, respectively (Figure 6). From the SAIL model, fractional LAI from 0 to 1 m^2 m^{-2} was also similar to the reflectance of a single leaf mixed with soil background reflectance. However, the NDVI for two stacked leaves that covered only one-half of the area (LAI = 1 m^2 m^{-2}) was only 75% of the NDVI of one leaf spread over the entire area (LAI also = 1 m^2 m^{-2}). Four stacked leaves covering only 25% of the area (LAI = 1 m^2 m^{-2}) is about half the NDVI of the one leaf spread over the entire area and that predicted by the SAIL model (Figure 6).

4. CONCLUSIONS

These results demonstrate that NDVI are more strongly related to vegetation cover and less strongly related to LAI. At continuous canopy cover, both with the SAIL model predictions and stacked leaf reflectances, changes in LAI from 1 to 2 m^2 m^{-2} were less important than changes in cover from 50% to 100%. Whereas these simulations were done for an planophile canopy rather than an erectophile grass canopy (because it is easier to stack sunflower leaves), these simulations were done to test hypotheses on NDVI/LAI suggested by the AVIRIS analyses for shortgrass steppe at CPER.

With vegetation cover, and by estimate bare soil cover, being determined using vegetation indices, then a key data requirement for rangeland management can be provided by remotely sensed data. Continuity of record from the Landsat Thematic Mapper provided with Landsat 7 will provide managers with some estimates of long-term rangeland sustainability. One the other hand, more work needs to be done in explaining how changes in cover over a growing season are related to primary production through changes in the fraction of absorbed photosynthetically active radiation.

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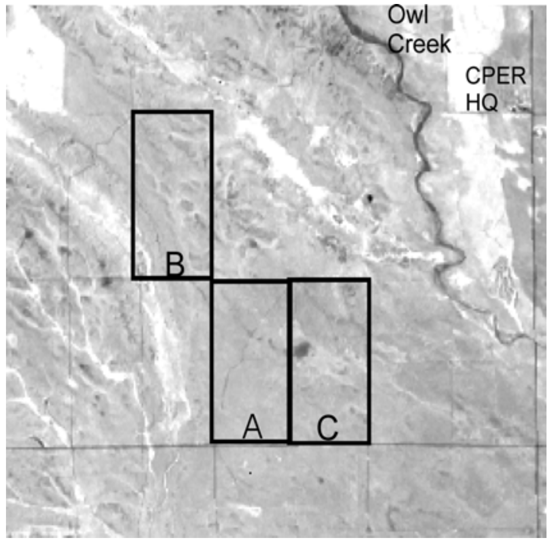

Figure 1. Grayscale NDVI image of the Central Plains Experimental Range from the 1995 AVIRIS data. The treatments are (A) light grazing, (B) medium grazing, and (C) heavy grazing. Un-grazed permanent plots are scattered over CPER.

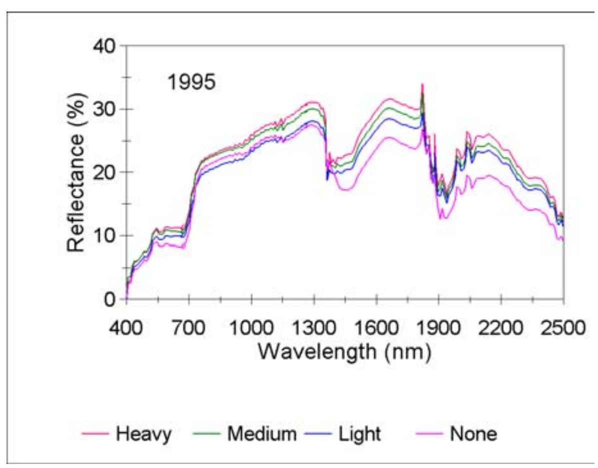

Figure 2. Average reflectance spectra for the four grazing treatments at CPER.

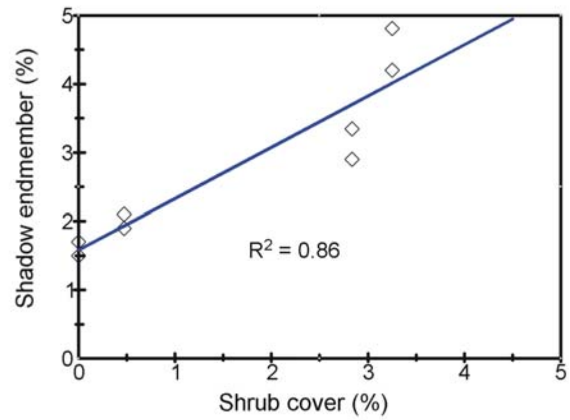

Figure 3. Relationship between the fraction of the shadow endmember and shrub cover from 1995 and 1998 AVIRIS data for the four grazing treatments.

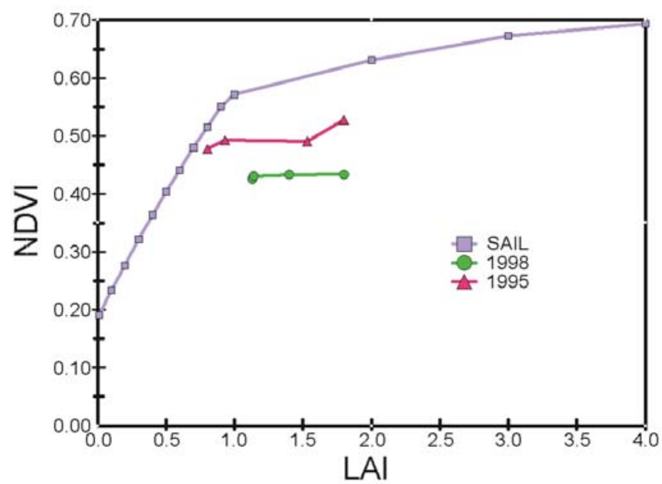

Figure 4. Relationship between NDVI and LAI for the four grazing treatments and simulations for an erectophile grass canopy using the SAIL model.

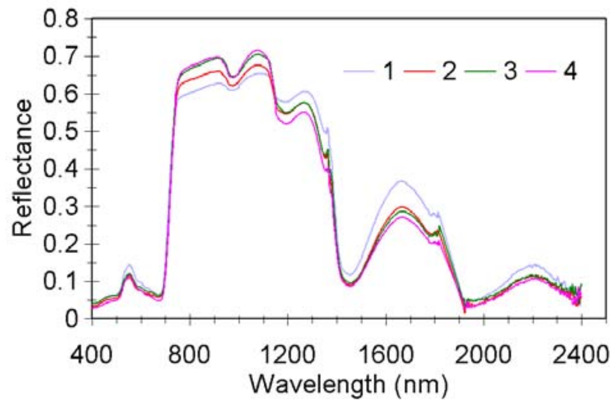

Figure 5. Reflectances of stacked *Helianthus annuus* (sunflower) leaves. Each reflectance is the average of 5 spectra.

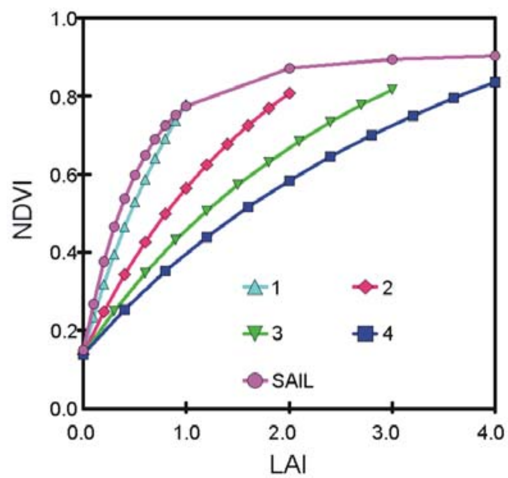

Figure 6. Relationships between NDVI and LAI for stacked *Helianthus annuus* leaves using a mixture model approach. Circles shows SAIL model predictions for *H. annuus* leaf reflectance and transmittance. Triangles show the NDVI of one leaf mixed at different proportions with bare soil. Diamonds show the NDVI of two stacked leaves mixed at different proportions with bare soil. Inverted triangles show the NDVI of three stacked leaves mixed at different proportions with bare soil. Squares show the NDVI of four stacked leaves mixed at different proportions with bare soil. NDVI for stacked leaves was calculated from the reflectances in Figure 5.